THE SKY.[1]

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Nothing in nature has impressed man more profoundly than the sky. Poet, painter, and philosopher, ancient and modern, each in his own way has striven to express its beauties. The ancient idea of the sky was that of an adamantine dome or vault upon which stars were studded, within which sun, moon, and planets moved. Upon Egyptian, Greek, and Roman, for whom the idea of an atmosphere as we now understand it did not exist, to whom the infinities of space were entirely closed, for whom there was no such thing as aërial perspective, the subtler beauties were lost. Yet from the earliest times the color of the sky drew the attention and admiration of all men, and expressions for it began to find their way into language and literature at a day when the color-sense, as we now know it, was largely undeveloped.[2]

The modern idea supplanted the old when the conception of an atmosphere became well established, and when modern astronomy had begun to give proper notions of the enormous distances and true motions of the heavenly orbs. The development

[1] Address of the retiring President. Delivered November 28, 1886, at the Emporia meeting of the Kansas Academy of Science.

[2] See Gladstone, Nineteenth Century, 1877, p. 367.

of these two ideas led to the distinction between the heavens outside of and the sky lying within our atmosphere. The rise of the distinction manifests itself on the one hand in painting; for whereas the early painters portrayed the sky as the ancients saw it, a vaulted dome of blue, hard and without depth, the growth of the art has been marked throughout by more and more successful attempts at atmospheric effect, at intangibility and depth. Where the earlier artists saw and painted only a blue surface, members of later schools — the landscape painters above all — began to indicate the truths of aërial perspective which had already forced themselves upon the attention of observing men, while it remained for a Turner and a Ruskin to give, with brush and pen, that fuller expression of the subtler beauties of the sky which increasing knowledge and the æsthetic training of generations have made possible to art.

In this, as in other ways, the development of science and of art have gone hand in hand, and it would be easy to trace the influence of Tycho Brahe and Galileo, of Otto von Guericke and Newton, upon the growth of æsthetics.

Of theories of the cause of the most obvious characteristic of the sky — its blueness — there have been no lack since men began to speculate. There was, however, no basis for intelligent theorizing until the experiments of Torricelli and von Guericke had shown the existence of an atmosphere, and the great chain of truths made clear by their investigations had had time to become familiar to the common mind. Even then there was no intelligible theory of colors, and the world must needs wait for Newton's prism before it could deal successfully with the problem of the color of the sky. The host of hypotheses which had been formed during the Middle Ages, were based upon so crude a conception of the nature of color that they melted instantly before the flood of light which was poured into the world of optics by Newton's analysis of the sunbeam. In the words inscribed upon a tablet at his birthplace —

> "Nature and Nature's laws lay hid in night;
> God said 'Let Newton be,' and all was light." [1]

A glance at these theories of the Middle Ages shows, nevertheless, how true it is that "the dream of one age is the science of the next," for it is easy to pick out from amid the debris of ruined structures fore-gleams of almost every theory which has appeared since Newton's time. Thus Leonardo da Vinci, in whom the highest attributes of the philosopher and artist were united in such a remarkable degree, regarded the azure as an optical illusion, or at least as subjective. Honoratus Fabri claimed that the color of the sky was due to reflexion from particles floating in the air, and this at a time when the existence of the atmosphere as we now know it had not been established. Fromond, and later, Funccius,[2] who wrote an entire work upon this subject, derived the color of the sky from a mixture of "much darkness and little light," and this opinion was long the ruling one. Otto von Guericke,[3] also, whose invention of the air-pump did much to further positive knowledge of the atmosphere, contended that black and white really give blue by mixture; and he described in evidence a variety of curious phenomena which the science of that day was not in position to explain.

At last these centuries of fruitless floundering in the dark came to an end. Newton's analysis of the sunbeam with the prism furnished the needed foundation for consistent theories in chromatics, and the problem of the color of the sky at once resolved itself into that of the action of the atmosphere upon the sunlight penetrating it. His method and its results alike are now the property of every schoolboy,

[1] Sir David Brewster's Life of Sir Isaac Newton, p. 305.
[2] See Fischer; Geschichte der Physik. Vol. II, p. 149.
[3] Von Guericke; Nova Experiment. Magdeb. Lib. IV, cap. XII, p. 147.

but it is with never-failing pleasure that lovers of nature to-day look back upon the experiments of that young philosopher, fellow of Cambridge, just turned twenty-four, whose mechanical ingenuity from boyhood and love of mathematics had already attracted favorable attention. Having bought a prism in the town, he took it home to his rooms to study the laws of refraction. The chamber was darkened, and the prism was placed in a ray of sunlight, which entered through a small, round hole cut in the shutter for that purpose. The diverted rays fell upon the wall, and then, for the first time recorded in the annals of science, was spread out that magnificent band of color — the solar spectrum. To understand Newton's mingled surprise and delight, we must remember that the only recognized function of the prism at that time was its power to bend a ray of light in accordance with Suell's law of refraction. The complex character of sunlight was unsuspected, dispersion undreamed of; nor did the truth dawn in Newton's mind at once. The unexpected display of color he attributed, as was in keeping with the teaching of the day, to some subtle action of the glass, and, having procured a second prism, he tried to increase the effect by passing the ray through it also. The further divergence of the spectral tints and their reunion in the original white of the sunbeam, according to the positions of the prisms, afforded the necessary hint, and Newton advanced by rapid strides to two epoch-making discoveries: That sunlight is the mixture of a vast number of colored rays differing from each other by insensible gradations of hue; and that these colors, being differently refracted, may be separated (dispersed) by the prism.

To appreciate the complete novelty of these results and the effects they were destined to produce upon the science of that day, we must remember that optics was in its very infancy; that the telescope itself, but little changed from the early forms devised by Galileo and the Dutch opticians, had been known but half a century, and that the first important step in its improvement was at this very time about to be taken by Newton himself. Although it was a period of great scientific activity, embracing such names as Gregory, Hooke, Sir Christopher Wren, and Boyle in England, and La Place, Leibnitz, Hugghens, and Bernouilli on the continent, the system of natural philosophy still in vogue was the Cartesian, the absurdities of which, day by day more manifest, were nevertheless inadequate to dethrone it until these and other remarkable advances had taken root, and the Newtonian philosophy, nearly half a century later, had finally become established in the universities. It was the beginning of a struggle against the extreme dogmatism of the period — a struggle which was to end in the introduction of experimental demonstrations, and so in the planting of the germ from which have sprung the great laboratory systems of the present time.

Starting from the complex character of sunlight as a foundation, the science of color in the hands of Newton and his followers made rapid progress, until the various ways in which, in nature, certain components of sunlight become isolated and appear as color, have become well known. We are thus able to divide all colors into two great classes — objective and subjective, and have learned that objective colors are formed either by the absorption of other rays or by interference; while subjective colors are due to physiological processes by means of which the eye is rendered more sensitive to certain colors than to the other components of the light which reaches the retina.

The blue of the sky is due, then, to absorption or to interference, or it is of subjective character. Newton[1] himself thought it due to interference, but it is cus-

[1] Newton; Optice, London, 1706.

tomary in our own times to ascribe the existence of the azure to atmospheric absorption.

In order to show the distinction between these blues, permit me to repeat a few well-known experiments. We have, in the rays of light issuing from the lantern, all those components which go to make up sunlight, only in slightly different proportions. If we place in the path of the ray a piece of cobalt glass, or this solution of sulphate of copper, nearly all the colors are absorbed, and their energy goes to heat the interposed medium. A few rays, however, are transmitted and fall upon the screen, of which the blue predominate to so great an extent as to determine the character of the resulting color, and to give us good examples of what are known as absorption blues.

There is, however, another way in which these other colors may be disposed of. Whenever white light is reflected from the surfaces of very minute transparent bodies, or of extremely thin films, the light-waves thus reflected interfere with each other, by which process some colors are destroyed, and others increased in intensity. One of the most convenient ways of showing this phenomenon, to which we owe many of the most striking and beautiful of nature's tints, the magical coloring of the peacock and the humming-bird, the varied hues of tropical beetles and butterflies, is by means of the familiar soap-bubble film. Here we have a substance which, without any intricate or difficult manipulation on our part, grows rapidly thinner and thinner, until it begins to show a play of interference colors of surpassing brilliancy. When we reflect the ray of the lantern from such a film and focus its image upon the screen, we have before us a shifting field of these interference colors. As the increasing tenuity of the film destroys each component of the ray in turn, each color of the spectrum in turn predominates, and we obtain at certain stages of the experiment interference blues of such intensity and delicacy that they may, with much more propriety, be compared with the blue of the sky than any absorption blue which can be produced by artificial means. What wonder that Newton, who made the first thorough investigation of this class of colors, and that many observers after him, should have ascribed the sky-blue to this source!

Experimental treatment of the subjective blues before a large audience is a much more difficult matter, and I shall content myself with a single very simple experiment, in illustration of one of the methods by which this class of colors may be produced. The distinguishing feature of the subjective blues is, that they do not depend upon the destruction of any portion of the spectrum by absorption or interference, but arise from temporary peculiarities of the retina of the eye, by which it becomes incapable, in one way or another, of receiving all the impressions which, in the normal retina, would be sent to the brain, there to be united in the complex sensation which we call white. The study of the color-sense shows that color-sensation, which appears at first sight exceedingly complicated, may be very simply explained by supposing the existence of three classes of nerve-fibers in the eye, each capable, whatever may be the character of the stimulus acting upon it, of transmitting a single message. One set conveys the impression which we call red, another green, and the third violet—the three primary color sensations by the union of which, in varying proportions, we are enabled to perceive the many thousands of hues which the outside world presents to vision. Now, the production of a subjective color depends upon this, that when white light enters the eye one or more of these nerves is unable to properly perform its function, so that the brain, instead of receiving the sensations due to white light, gets an incomplete impression, in which some necessary component is enfeebled or missing. Whenever this happens the observer perceives color, the nature of which depends upon which nerve it is that fails to act. The sole distinction, then, between objective and subjective colors lies in the man-

ner in which the missing components are destroyed: when by absorption or interference before the ray enters the eye, the color is said to be objective; when within the eye, by the failure of certain portions of the optic nerve to perform their function, we term the thereby-modified sensation conveyed to the brain a subjective color. The influence of different portions of the spectrum upon these three sets of nerves, has been studied by Helmholtz,[1] Maxwell,[2] and others, and the result of their very laborious investigation is shown in the accompanying diagram. (Fig. 1.)

Each wave-length of the visible spectrum affects all three nerves, although in very different degrees. And so all colors, even to the tints of the "pure" spectrum, are really trifold, consisting of a mixture of these three primary color sensations. When all three nerves are equally affected, the result is white; and the color differs from white whenever the impression upon one set of nerves is enfeebled or unduly strengthened.

These color nerves in the eye become temporarily weakened whenever they are strongly stimulated, and their temporary enfeeblement is the chief cause of subjective color. Contrast effects are among the most familiar examples of subjective color sensation. They are always present, serving to heighten or to diminish brilliancy of hue, according to the arrangement of the colors upon which we gaze. If you will stare intently for a moment upon that patch of yellow light upon the screen, you will see that when I withdraw the bit of glass which caused it, from the field of the lantern, that portion of the screen, really a pure white, becomes suffused with an indescribably delicate shade of blue. The blue is produced by white light from the screen entering your eyes, the red and green-transmitting nerves of which have been somewhat fatigued by exposure to yellow, which is principally made up of these two compounds. The nerves which transmit violet have been resting, meantime, because those portions of the lantern's rays which would have affected them were absorbed by the yellow glass; and so the message carried to your brain, instead of consisting equally of the impressions of red, green and violet, now consists chiefly of the last. The violet-carrying nerves are unusually active after their short period of repose, while those burdened with the red and green are fatigued by exposure, and scarcely act at all. The resulting sensation is of an excess of violet light, mixed with green and red to just the extent necessary to produce the subtle and very delightful blue you have just seen. The effect vanishes as the tired nerves regain their normal sensitiveness, and the white screen regains its ordinary appearance.

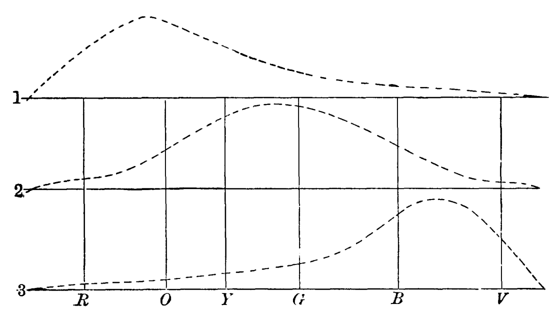

FIG 1.

After this brief discussion of the causes to which color is due, we are ready to consider some of the theories of the color of the sky which have prevailed in more recent times.

Newton's hypothesis, that sky-blue is produced by inference, has been abandoned long since, on account of difficulties which we cannot touch upon here, and has been supplanted by the simpler theory that the color is due to atmospheric absorption

[1] Helmholtz: Handbuch der physiologischen Optik, p. 317.
[2] Maxwell: Philosophical Transactions, vol. CL, p. 78.

of the less refrangible rays. Many attempts have been made to fix upon the precise medium to which this absorption may be due.

The fact that water is always present in our atmosphere, in a state of fine subdivision, has naturally led philosophers to look to it as the absorbing medium. The establishment of this theory depends, however, upon the ability to show that sunlight, when viewed through a sufficiently thick layer of water, appears blue; but the very numerous experiments upon this subject have given a great variety of results. Many waters, notably those of Lake Geneva and of the deep sea, have this blue color to a marked degree. Others, when viewed by transmitted light, appear green, yellowish, and even brown. The presence of impurities, even in almost inconceivably minute quantities, has been found to produce striking changes of color. Thus water newly distilled is blue, but, upon standing even for a few hours in perfectly clean vessels, it becomes green, yellow, and even brown; changes which have been traced to the presence in increasing numbers of microscopic organisms, so minute and so transparent as to test the microscope in the severest manner. Loret, who has studied this subject exhaustively, in the hope of solving the problem of the color of the water of Lake Geneva, finds that otherwise pure water containing silica produces absorption blues, to which he ascribes the blue color of newly-distilled water.[1] The

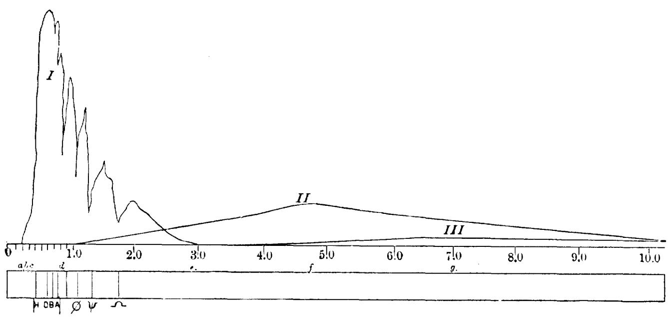

FIG. 2.[2]

addition of other impurities, especially iron, such as give a yellow instead of a white residue upon evaporation, convert this blue into green, and ultimately into brown. The presence of minute quantities of silica in the water of the atmosphere has led him to ascribe the color of the sky to the presence of this element in the water floating in the air.

The gaseous components of our atmosphere have also been looked to as the absorbing media to which we owe the color of the sky, and one of these — ozone — having been recently found to possess an absorption spectrum rich in violet rays, ozone has been declared the substance to which the azure is due.

The long prevalent opinion that the atmosphere, taken as a whole, transmits the violet rays more readily than those of longer wave-length, has been controverted by the investigations of our countryman, Professor Langley, who brought to bear upon this very difficult problem a new instrument of his own invention, an apparatus of hitherto undreamed of delicacy. Langley's instrument — the bolometer — makes it possible to measure radiant energy accurately by electrical means, even when the rays are so feeble as to be quite out of the reach of the most sensitive of the former apparatus devised for this purpose. Scarcely exceeded in delicacy by the eye itself, the bolometer is not confined like the eye to impressions from the very limited

[1] See E. Ray Lancaster, Nature. Vol. II, p. 235.

[2] From Langley's Monograph; Researches on Solar Heat and its Absorption by the Earth's Atmosphere: Professional Papers of the Signal Service, No. 15.

series of rays which comprise the visible spectrum. It is affected by all wave-lengths in proportion to their intensity, and in the skillful hands of its inventor it has been the means of bringing to our knowledge a vast and important series of heat-waves hitherto undetected. By its use it is now possible to analyze and study the radiation from bodies of low temperature — even below the freezing point of water — with almost the same certainty and precision as that from substances in a high state of incandescence. The diagram now on the screen (Fig. 2) shows the results of some measurements by Professor Langley of the radiation from substances at 100° C. and —2° C. The curves show the energy of each wave-length emitted, and present to our view spectral regions far beyond the infra-red of the solar spectrum. The very limited region lying between *A* and *H*, comprises those rays which are capable of affecting the human retina. The most refined methods previously known to science had extended our acquaintance with the longer wave-lengths only to the point marked Ω. Beyond lay the still longer waves due to radiation at low temperatures, the wave-lengths and intensities of which are indicated in these curves.

Armed with this wonderful instrument, and possessed of skill and perseverance given to few, Professor Langley made exhaustive studies of the quality of the sun's rays after they had been sifted by passing through the miles of atmosphere above his observatory at Alleghany. He then took his instruments and a corps of trained assistants across the continent to a remote point in the American desert which was known to possess an atmosphere of unrivaled purity, established a temporary station at the base of Mt. Whitney, and repeated his measurements there.

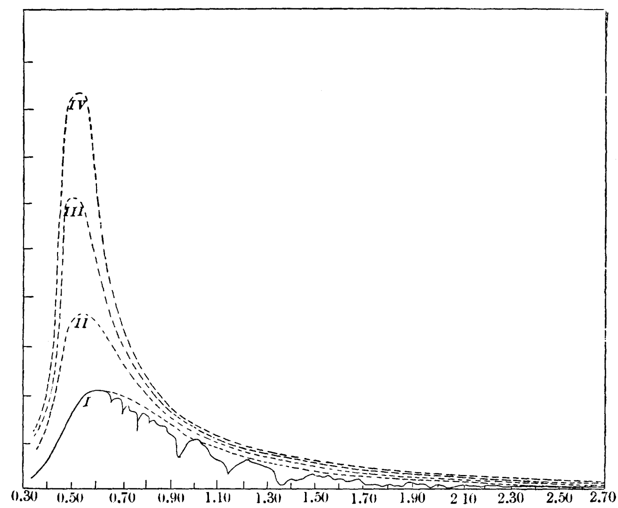

FIG. 3.[1]

The party then ascended the almost inaccessible peak to an elevation of 14,000 feet, and with nearly half the earth's atmosphere below them, succeeded in making a determination of the quality of sunlight at this high station. Of the dangers and difficulties of bringing across the desert and up the mountain all the delicate apparatus necessary to such a research, only those who accompanied the expedition can form any adequate conception. The published accounts furnish one of the most romantic passages in the history of science.

The energy curves of sunlight obtained at these three stations (Fig. 3) are of the highest scientific interest. They show beyond dispute that the earth's atmosphere absorbs much more of the violet and other more refrangible rays than of the red wave-lengths; so that could we ascend entirely beyond the atmosphere, sun and stars would appear much bluer than they do at the surface of the earth. It seems

[1] From Langley's monograph; l. c.

quite certain, in the light of these researches, that we look out into the heavens through a reddish opalescent haze, which greatly modifies the quality of the sun's rays to us, producing an effect not unlike that of Indian summer.

Professor Langley's study of the absorption spectrum of the earth's atmosphere has simplified the problem of the color of the sky by excluding a number of hypotheses which are incompatible with his results. It necessitates our looking for the blueness of the sky in some action of the atmosphere other than absorption, since his experiments show conclusively that sunlight becomes less and less blue by transmission through the air. Much light has been thrown upon the process by which the azure may be formed, by Tyndall's famous experiment, known as the "*artificial sky*." While studying the decomposition of vapors by sunlight, Tyndall had occasion to send a powerful ray of white light through a tube containing a certain organic vapor (the nitrite of amyl). This vapor was broken up by the light, and some of its constituents were precipitated in the form of a fine cloud, which grew denser and denser as the experiment proceeded. This cloud when forming, presented a beautiful blue appearance strikingly suggestive of the open sky, which gave way as the precipitate increased in intensity, to a milky whiteness.[1] This incipient cloud Tyndall called his artificial sky, and the belief that it is very closely allied in character to the true sky, although the substances from which the color arises are of course not the same, is very much strengthened by the evidence of the polariscope.

One of the most puzzling features of the light reflected from the sky is its polarization, which differs from that of the light reflected by water, or indeed by any solid or liquid substance. Now the angle of maximum polarization of the artificial sky was found to be the same as that of the real sky, and the same thing has since been shown to be characteristic of the rays reflected by many other substances when in a state of exceedingly fine subdivision.[2]

A similar blue has also been produced by Lord Rayleigh, by the precipitation of sulphur from solutions of the hyposulphite of soda by means of hydrochloric acid. This experiment is so simple, that I will try to reproduce it for your benefit.

Here, as in Tyndall's experiment, the blue is most marked at the moment when the cloud is beginning to form; and it is speedily supplanted by the milky appearance characteristic of opalescent solutions. It is the peculiarity of all the solutions capable of giving the blue cloud to transmit red light and absorb the shorter wavelengths. When we pass the rays of the lantern through a cell containing the milky liquid obtained in this experiment, the white light upon the screen becomes ruddy, and the effect upon the rays passing through the solution is similar to that which the earth's atmosphere exerts upon the rays of the sun in their journey to the surface of our planet. We live, in a word, at the bottom of a vast sea of opalescent material, which transmits the sunbeams to us with their blue and violet components enormously reduced, and which reflects, from the multitudes of exceedingly small particles suspended in it, light which produces upon the retina the same effect as the light reflected by the "artificial sky" of Tyndall, or of Rayleigh. I shall show you presently that true sky light is almost identical in composition with the light from these artificial skies.

The experimental evidence concerning the real nature of these colors is exceedingly meager. A variety of observations of my own led me some years ago to call in question the generally accepted view that the blue of the sky is of objective character like that transmitted by cobalt glass or produced by reflexion from such pig-

[1] Tyndall; Fragments of Science, p. 93; also, Contributions to the Domain of Molecular Physics, p. 425.

[2] See Burch; "Some Experiments on Flame;" Nature, vol. 31, p. 272.

ments as indigo and ultramarine. That the world should be flooded with light of the sky's deepest blue, and that nevertheless we should be spared even a trace of the very peculiar effects produced when we substitute blue glass in the windows of a room for that of the usual neutral tint, or color the walls with ultramarine, is, to say the least, remarkable. One might suppose that whenever light from the sky, undiluted by the direct rays of the sun, became the chief source of illumination, its influence would be obvious to the most careless observer; modifying the colors of every object, and producing a thousand marked changes in the aspects of nature. The reverse is true, and even the multitude of less obvious phenomena with which only the artist and the special student of color might expect to meet with in consequence of the blueness of light from the sky are lacking. In clear weather the daylight which penetrates every nook and cranny of the inhabited world is sky light, save where the direct rays of the sun may chance to fall, and it is found to vary from direct sunlight in no respect, excepting in intensity.

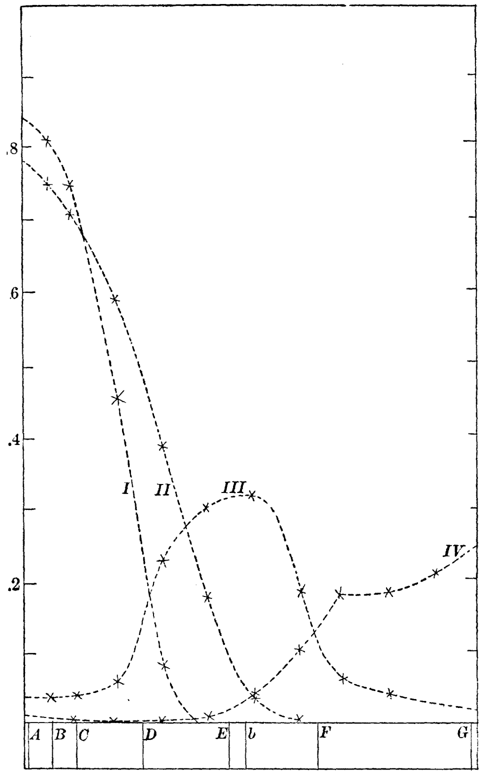

FIG. 4.

We are not in the habit of assigning to it even that degree of blueness which in the popular mind is associated with moonlight. Even those who use the spectroscope have long since noticed the absence of any marked difference between light from the sun, that reflected from white clouds, and that which reaches us from the open sky.[1]

In the spectrophotometer we have a modification of the spectroscope by means of which it is possible to compare the intensity of spectra, wave-length for wave-length. An analysis of colors with this instrument shows all of them, excepting the tints of the pure spectrum, to be modifications of white in which one portion or another has been destroyed by absorption within the substance to which the color belongs. Upon the screen you see the spectrophotometric curves characteristic of four well-known pigments, viz.: red lead, chrome yellow, chrome green, and artificial ultramarine, (Fig. 4.)[2] Such curves, indicating as they do the relative intensities

[1] In exception to this statement stand, however, observations by Rayleigh, (Philosophical Magazine, 1871,) who found in the spectrum of the open sky a *slight* excess of the more refrangible wave-lengths, and more recently by H. C. Vogel, (Photographische Mittheilungen 20, 1883, p. 74,) who found evidence in photographed spectra of the sun and of the sky, of a preponderance of ultra violet rays in the latter.

[2] Taken from the author's paper entitled, "A Spectrophotometric Study of Pigments," Am. Journal of Science, vol. 28, 1884.

of all the various rays which enter into the composition of the colors in question, give no definite knowledge of the nature of the light to which pigments owe their characteristic hues.

Soon after the completion of the measurements the results of which are indicated in these four curves, it occurred to me that an important step toward the solution of the problem of the color of the sky might be made by directing the spectrophotometer to the sky itself, and comparing its spectrum throughout with that of some neutral white substance capable of reflecting all colors equally well. I attempted such an analysis in the spring of 1885. It is not my purpose to enter here into the details of that research. Some of the difficulties encountered in the selection of a white substance suitable for the comparison will be described in my paper entitled "Black and White." [See pp. 37–44 of these Transactions.] The pigment finally adopted was the carbonate of magnesium. This analysis brought out the remarkable fact that the light which the sky reflects to us, although differing from direct sunlight to a measurable extent, yet corresponds with the latter quite as closely as does that reflected by any white pigment which I have studied. Its deviation from true whiteness, which varies from day to day and from hour to hour, does not always consist as the appearance of the sky would lead us to suppose, in any marked excess of blue rays. Indeed, the first sky which I subjected to measurement was found to be deficient in the very rays upon which the existence of an objective blue depends. The curves now shown upon the screen are those pertaining to the spectrum of the sky on April 28, May 1, and May 4, 1885. Light reflected from a perfectly white body would be represented by the horizontal line. (Fig. 5.) Deviations from that line denote excess or deficiency of the rays belonging to the corresponding regions of the spectrum, as indicated by the Fraunhofer lines at the bottom of the diagram.

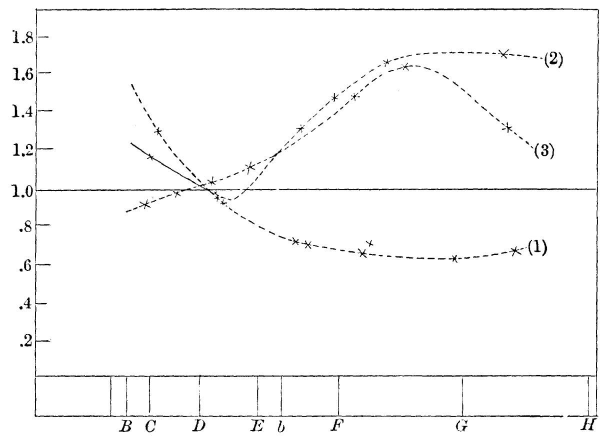

FIG. 5.

On April 28 (see Curve 1, Fig. 5), the sky was of more than average blueness, so far as the eye could judge, yet its spectrum was found to possess more red and less blue and violet than belong to a true white, being in this respect almost identical with the magnesium carbonate with which it was compared. On the first of May (see Curve 2, Fig. 5), a sky, to the unaided eye very like the first, showed a decided excess of blue; while on the 4th of May (see Curve 3, Fig. 5), the predominating color, as shown by the spectrophotometer, was greenish-blue, the violet rays being comparatively feeble.

In order to understand the extent to which these variations from true whiteness were capable of influencing the hue of the sky as observed by the unaided eye, let us compare these curves with those obtained by the same method and with the same instrument from various substances, which had been selected because of their unusual whiteness. Specimens of magnesium carbonate, of plaster of Paris and of

white paper, which had been treated in the process of manufacture with an almost infinitesimal amount of some blue pigment for the purpose of counteracting the slightly yellowish cast common to these substances in their natural state, and to give them brilliancy, were subjected to analysis with the spectrophotometer. It will be seen from the curves obtained from their spectra (Fig. 6), that they all vary quite as much from true whiteness as does the sky, and yet they had been selected as uncommonly pure specimens of white pigments in my search for a suitable standard of comparison; and the existence of the blue adulterant had been entirely unsuspected until revealed by measurements with the spectrophotometer.

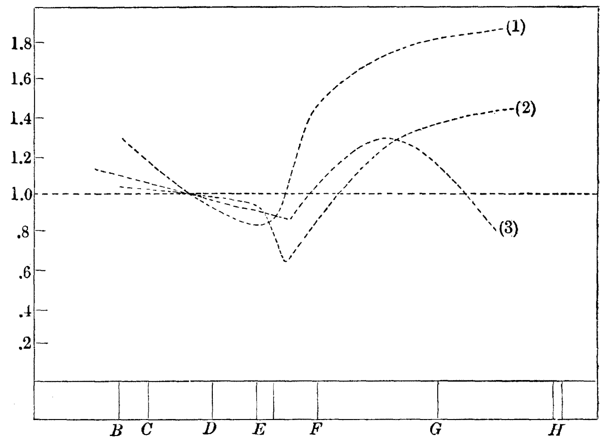

FIG. 6.

The "artificial sky" of Lord Rayleigh and the beautiful blue blowpipe films of antimony oxide, so familiar to the chemists when studied with the spectrophotometer, exhibited the same peculiarity as the azure of the true sky, excepting that these opalescent blues possessed very faint spectra which differed less from that of an absolutely white substance than any of the objects which I had analyzed.

Was Leonardo da Vinci right, then, in deeming the azure an optical illusion, or as we should now call it, a "subjective blue"? I know of no other interpretation of the results of the spectrophotometric analyses to which I have just alluded. The subject is fraught with great experimental difficulties, and we have still almost everything to learn concerning the color of the sky.

Should these measurements meet with final corroboration, and the subjective character of the azure be thereby established, two important elements in the production of the blueness of the sky will be found. In the first place, a true white is much bluer than the standards of whiteness which we have been forced to adopt in the absence of anything better; and in the second place, the well-known sensitiveness of the eye to the violet components of all colors of low intensity increases this blue of contrast to an extent which we little realize.[1] That these two factors are always at work intensifying the azure, is already beyond question. To assert that they are the only important factors, and that the excess of violet rays in the spectrum of light from the sky plays no essential part in the production of its color, upon evidence derived from a limited set of experiments like my own, would be premature. We must await more exhaustive researches at the hands of those competent to assail successfully this great problem, before we can hope for a final decision between the various theories which I have attempted to touch upon this evening.

UNIVERSITY OF KANSAS, November, 1886.

[1] See Albert; Annalen der Physik und Chemie, N. F. 16, p. 129.